Postharvest Pathology

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Introduction: Losses caused by postharvest diseases are greater than generally realized because the value of fresh fruits and vegetables increases several-fold while passing from the field to the consumer (Eckert and Sommer, 1967). Postharvest losses are estimated to range from 10 to 30% per year despite the use of modern storage facilities and techniques (Harvey, 1978).

Postharvest diseases affect a wide variety of crops particularly in developing countries which lack sophisticated postharvest storage facilities (Jeffries and Jeger, 1990). Infection by fungi and bacteria may occur during the growing season, at harvest time, during handling, storage, transport and marketing, or even after purchase by the consumer (Dennis, 1983). The reduction of losses in perishable food crops because of postharvest diseases has become a major objective of international organizations (Kelman, 1989). The reality is that there is a portending food crisis that will require the concerted efforts of all who are involved in food production to double their efforts. In fact, to adequately feed the world's expected 10 billion people within the next 40 to 50 years, food production efficiency and distribution will need to be improved immensely (Campbell, 1998).

Specific causes of postharvest losses of fruits and vegetables may be classed as parasitic, nonparasitic, or physical (Cappellini and Ceponis, 1984) This chapter deals with the parasitic causes that are of microbiological origin that begin as latent infections before harvest or occur at or after harvest during storage. Fungi are more commonly found attacking fruit and bacteria are more common as postharvest pathogens of vegetables. This chapter will provide a general overview of the subject touching on noteworthy research where it can be used to illustrate postharvest pathology. The reader is encouraged to consult the references for specific information on the topics that are covered.

Preharvest Factors that Influence Postharvest Pathology: Postharvest losses vary each year. Prevailing weather while the crop is growing and at harvest contribute greatly to the possibility of decay. Certain cultivars are more prone to decay than are others to specific pathogens. In a recent study, it was found that resistance of major apple cultivars to the fungi that cause blue mold, gray mold, bull's-eye rot, and Mucor rot was dependent on cultivar (Spotts et al., 1999). Condition of the crop, as determined by fertilizer and soil factors, are very important in susceptibility of the crop to disease. Maturity of the crop at harvest, handling and type of storage have a great deal of influence on how long the crop can be stored without decay. Examples are given below that demonstrate how these preharvest factors lead to disease in specific crops.

Weather: Weather affects many factors related to plant diseases, from the amount of inoculum that overwinters successfully to the amount of pesticide residue that remains on the crop at harvest (Conway, 1984). Abundant inoculum and favorable conditions for infection during the season often result in heavy infection by the time the produce is harvested. For example, conidia of the fungus that causes bull's-eye rot are rain dispersed from cankers and infected bark to fruit especially if rainfall is prolonged near harvest time, causing rotten fruit in cold storage several months later (Spotts, 1990).

Pinpoint or storage scab of apple caused by the same fungus that causes apple scab, and gray mold caused by the fungus *Botrytis cinerea*, are also very much influenced by the weather. Storage scab only occurs in years with unusually wet Summers and early Falls, when the fruit remain wet for a day or more.

These late season infections may not become visible until the apples are in storage (Pierson et al., 1971). Flowers and fruit are infected by *Botrytis cinerea* most effectively when it is wet. For example, in grapes infection occurs at 15 to 20 ºC (59 to 68 ºF) in the presence of free water after approximately 15 h (Bulit and Dubos, 1988). In wet seasons strawberries and raspberry crops may be harvested in apparently sound condition, only to decay during tansit and marketing (Snowdon, 1990).

Postharvest decay involves further development of pre-harvest infections together with new infections arising from germination of spores on the fruit surface. From these examples it is apparent that decay often has a weather component making thorough weather records an important source of information for predicting possible decay in storage.

Physiological Condition: Condition of produce at harvest determines how long the crop can be safely stored. For example, apples are picked slightly immature to ensure that they can be stored safely for several months. The onset of ripening and senescence in various fruit and vegetables renders them more susceptible to infection by pathogens (Kader, 1985). On the other hand, fruit and vegetables can be made less prone to decay by management of crop nutrition. For example, calcium has been more closely related to disease resistance than any other cation associated with the cell wall (Sams, 1994).

In a study on the effect of increased flesh calciumcontent of apples on storage decay fruit were treated with solutions of $CaCl_2$ by dipping, vacuum, or pressure infiltration. Both vacuum and pressure infiltration increased calcium content of the fruit sufficiently to significantly reduce decay (Conway, 1982). Increased calcium contents in potatoes and peaches have also been documented with reduced postharvest decay (Conway, 1989). In general, produce containing adequate levels of calcium do not develop physiological disorders and can be stored longer before they breakdown or decay. Conversely, high nitrogen content in fruit predisposes them to decay (Conway, 1984). In pears, it has been found that management of trees for low nitrogen and high calcium in the fruit reduced severity of postharvest fungal decay (Sugar et al., 1992). Apple cultivars can be selected for resistance to certain postharvest diseases (Spotts et al., 1999). For example, 'Royal Gala' is extremely resistant to wound pathogens, 'Granny Smith' to skin punctures, and 'Braeburn' to infiltration of fungal spores into the core.

Fungicide Sprays: Certain pre-harvest sprays are known to reduce decay in storage. Several studies have been done on the effectiveness of pre-harvest ziram fungicide application on pome fruit and show an average reduction in decay of about 25 to 50% with a single spray (Sugar and Spotts, 1995). Iprodione has been used for several years as a pre-harvest spray 1 day before harvest to prevent infection of stone fruit by *Monilinia* spp. In combination with wax and/or oil its decay control spectrum is increased and it will also control postharvest fungi such as *Rhizopus,* and *Alternaria* (Ogawa, et al. 1992). Several new fungicides that are being developed, or have recently been registered promise to protect produce from a number of diseases after harvest. For example, cyprodinil prevented gray mold infection in apple 3 mo after it was applied (Sholberg and Bedford, 1999). The new class of strobilurin fungicides promise to provide postharvest control of several diseases in fruit and vegetables. They are especially effective against fruit scab on apples and should reduce the presence of pin point scab in storage.

Postharvest Factors that Influence Decay:

Packing Sanitation: It is important to maintain sanitary conditions in all areas where produce is packed. Organic matter (culls, extraneous plant parts, soil) can act as substrates for decay-causing pathogens. For example, in apple and pear packinghouses, the flumes and dump tank accumulate spores (Blanpied and Purnasiri, 1968) and may act as sources of contamination if steps are not taken to destroy or remove them.

Chlorine readily kills microorganisms suspended in dump tanks and flumes if the amount of available chlorine is adequate. A level of 50 to 100 $\mu L\ L^{-1}$ of active chlorine provides excellent fungicidal activity (Spotts and Peters, 1980). Chlorine measured as hypochlorous acid can be obtained by adding chlorine gas, sodium hypochlorite, or dry calcium hypochlorite. Although chlorine effectively kills spores in water it does not protect wounded tissue against subsequent infection from spores lodged in wounds. Organic matter in the water inactivates chlorine, and levels of chlorine must be constantly monitored. The use of a sand filter in association with chlorination improves its efficiency probably because it removes organic matter (Sholberg and Owen, 1990). Chlorine is sensitive to pH (Dychdala 1983); hypochlorite solutions with higher pH values (7.5 to 8.5) are more stable but less fungicidal, whereas at lower pH values (5.5 to 6.5) the solutions are less stable but more fungicidal.

Recently, chlorine dioxide has replaced chlorine in some sanitizing processes, because several disadvantages limit the use of chlorine, including its unpleasant odor. Chlorine dioxide is not corrosive and is effective over a wide pH range (Spotts and Peters, 1980). Recently, in precisely controlled tests in water or as a foam, chlorine dioxide was found to be effective against common postharvest decay fungi on fruit packinghouse surfaces (Roberts and Reymond, 1994). Peracetic acid is another material that could be used (Mari et al., 1999). It has greater stability and faster biocidal properties than chlorine dioxide, but is more corrosive.

The search goes on for effective and economical sanitizing agents. New and old products alike, are continually being evaluated under present day packing operations. Interest in ozone has been rekindled with development of more efficient ozone generators. Acetic acid in the form of a gas is being evaluated for possible use as a sanitizing agent on several crops (Sholberg, 1998). It was as effective as SO_2 in preventing Gray Mold decay in table grapes stored for 2 mo (Sholberg et al., 1996).

Postharvest Treatments: Products used for postharvest decay control should only be used after the following critical points are considered (Ogawa and Manji, 1984):

Type of pathogen involved in the decay.
Location of the pathogen in the produce.
Best time for application of the treatment.
Maturity of the host.
Environment during storage, transportation and marketing of the produce. Specific materials are selected based on these conditions and fall into either chemical or biological categories listed below.

Fungicide treatments: Several fungicides are presently used as postharvest treatments for control of a wide spectrum of decay-causing microorganisms. However, when compared to preharvest pest control products the number is very small. Many former products that were used after harvest are no longer permitted because of concerns with residues and possible toxic effects, the most notable being products that contained benomyl. Other products have been lost as effective controls due to development of resistance by the target pathogen. For example, intensive and continuous use of fungicides for control of blue and green mold on citrus has led to resistance by the causal pathogens of these diseases (Eckert, 1988). Resistance has been reported in many other crops to several different fungicides with different modes of action (Delp, 1988). Resistance development continues to be an important problem. It has led to the "Fungicide Resistance Action Committee" (FRAC, 1998), a cooperative effort between the various producers of fungicides to delay resistance by recommending specific management guidelines.

Examples of postharvest chemical treatments that are presently used are thiabendazole, dichloran, and imazalil. However, resistance to thiabendazole and imazalil is widespread (Holmes and Eckert, 1999) and their use as effective materials is declining. Preservatives or antimicrobial food additives are not generally thought of as postharvest treatments but they do control decay, and in some cases are the only means of control. These products include sodium benzoate, the parabens, sorbic acid, propionic acid, SO_2, acetic acid, nitrites and nitrates, and antibiotics such as nisin (Chichester and Tanner, 1972). For example, in California gray mold of stored table grapes is prevented by fumigation with SO_2 (Luvisi et al., 1992). The demand for new postharvest fungicide treatments is strong, especially since the loss of iprodione in 1996.

Fludioxinil was granted an emergency registration in 1998 to curb potential losses in nectarines, peaches, and plums that would have resulted (Forster and Adaskaveg, 1999). Not all postharvest pathogens are presently controlled by materials that are available. For example, *Mucor piriformis*, a major postharvest pathogen of apples and Winter pears in the Pacific Northwest is not controlled by any registered fungicide (Spotts and Dobson, 1989). There is a dire need for new postharvest fungicide treatments that could in part be alleviated by the use of biological control agents (Wisniewski and Wilson, 1992; Utkhede and Sholberg, 1993).

Biological Control of Postharvest Pathogens: Postharvest biological control is a relatively new approach and offers several advantages over conventional biological control (Wilson and Pusey, 1985; Pusey, 1996):

Exact environmental conditions can be established and maintained.
The biocontrol agent can be targeted much more efficiently.
Expensive control procedures are cost-effective on harvested food.

Several biological control agents have been developed in recent years, and a few have actually been registered for use on fruit crops. The first biological control agent developed for postharvest use was a strain of *Bacillus subtilis* (Pusey and Wilson, 1984). It controlled peach brown rot, but when a commercial formulation of the bacterium was made, adequate disease control was not obtained (Pusey, 1989). More recently, a strain of *Pseudomonas syringae* van Hall was found that controlled both Blue and Gray Mold of pome fruit (Janisiewicz and Marchi, 1992). It was subsequently registered, and is now sold commercially for postharvest disease control (Janisiewicz and Jeffers, 1997).

Other bacterial microorganisms are being developed for postharvest disease control. For example, strains of *Bacillus pumilus* and *Pseudomonas fluorescens* have been identified that exhibit successful control of *B. cinerea* in field trials of strawberry (Swalding and Jeffries, 1998). Yeasts such as *Pichia guilliermondii* (Wisniewski et al., 1991) and *Cryptoccocus laurentii,* a yeast that occurs naturally on apple leaves, buds, and fruit (Roberts, 1990) were the first to be applied for control of postharvest decay on fruit. The yeast, *Candida oleophilia* has been registered for control of postharvest decay on fruit crops. The yeasts, *Cryptococcus infirmo-minutus* and *Candida sake* successfully control brown rot and blue mold on sweet cherry (Spotts et al., 1998), and three diseases of apple (Vinas et al., 1998), respectively, and may be developed commercially.

Although there is no doubt that biocontrols are effective, they do not always give consistent results. This could be because biocontrol efficacy is so directly affected by the amount of pathogen inoculum present (Roberts, 1994). Compatibility with chemicals used during handling is also important. Indications are that biological control agents must be combined with other disease control strategies if they are to provide acceptable control.

Irradiation for Postharvest Decay Ccontrol: Although ultraviolet light has a lethal effect on bacteria and fungi that are exposed to the direct rays, there is no evidence that it reduces decay of packaged fruits and vegetables (Hardenburg et al., 1986). More recently, low doses of ultraviolet light (254 nm UV-C) irradiation reduced postharvest brown rot of peaches (Stevens et al., 1998). In this case, the low dose ultraviolet light treatments had two effects on brown rot development; reduction in the inoculum of the pathogen and induced resistance in the host. However, it has not become a practical postharvest treatment as yet and requires more research.

Gamma radiation has been studied for controlling decay, disinfestation, and extending the storage and shelf-life of fresh fruits and vegetables. Dosages of 1.5 to 2 kilogray (kGy), and some cases 3.0 kGy (300 krad), have been effective in controlling decay in several products (Hardenburg et al., 1986). A dose of 250 Gy has an adverse effect on grapefruits increasing skin pitting, scald, and decay. Low doses of 150 for fruit flies and 250 gray (Gy) for codling moth are acceptable quarantine procedures (Meheriuk and Gaunce, 1994). Commercial application of gamma radiation is limited due to the cost and size of equipment needed for the treatment and to uncertainty about the acceptability of irradiated foods to the consumer (Hardenburg et al., 1986). Gamma irradiation may be used more in the future once methyl bromide is no longer available to control insect infestation in stored products. All uses of methyl bromide are being phased out to avoid any further damage to the protective layer of ozone surrounding the earth.

Effect of Storage Environment on Postharvest Decay: Commercial producers and handlers modify temperature, RH, and atmospheric composition during prestorage, storage, and transit to control decay (Spotts, 1984). For optimum decay control, two or more factors often are modified simultaneously.

Temperature and RH: Proper management of temperature is so critical to postharvest disease control that all other treatments can be considered as supplements to refrigeration (Sommer, 1989). Fruit rot fungi generally grow optimally at 20 to 25 ºC (68 to 77 °F) and can be conveniently divided into those with a growth minimum of 5 to 10 ºC (41 to 50 °F) , or -6 to 0 ºC (21.2 to 32 °F). Fungi with a minimum growth temperature below -2 ºC (28.4 °F) cannot be completely stopped by refrigeration without freezing fruit. However, temperatures as low as possible are desirable because they significantly slow growth and thus reduce decay.

High temperature may be used to control postharvest decay on crops that are injured by low temperatures such as mango, papaya, pepper, and tomato (Spotts, 1984). Although hot water generally is more effective, hot air has been used to control decay in crops that are injured by hot water. Heating of pears at temperatures from 21 to 38 ºC (69.8 to 100.4 °F) for 1 to 7 days reduced postharvest decay (Spotts and Chen, 1987). Decay in 'Golden Delicious' apples was reduced by exposure to 38 ºC (100.4 °F) for 4 days (Sams et al., 1993) and virtually eliminated when treated after inoculation (Fallik et al., 1995; Klien et al., 1997). Heat treatment eliminates incipient infections and improves coverage by fungicides (Couey, 1989). The primary obstacle to the widespread use of heat to control postharvest fruit diseases or insect infestation is the sensitivity of many fruit to the temperatures required for effective treatment.

Both low and high RH have been related to postharvest decay control. Perforated polyethylene bags for fruit and vegetable storage create RH about 5 to 10% above that in storage rooms. Although shrivel and weight loss are reduced, decay may be increased (Spotts, 1984). Crops such as apples and pears with well-developed cuticle and epidermis, tolerate lower RH levels that help prevent storage decay. Often fungal spore germination is inhibited at low RH, and small differences in RH can have significant effects in relation to the degree of postharvest decay (Spotts and Peters, 1981).

Modified or Controlled Atmospheres: Alterations in O_2 and CO_2 concentrations are sometimes provided around fruit and vegetables (Spotts, 1984). With close control of these gases, the synthetic atmosphere is commonly called a controlled atmosphere; the term modified atmosphere is used when there is little possibility of adjusting gas composition during storage or transportation (Sommer, 1989). Because the pathogen respires as does produce, lowering the O_2 or raising the CO_2 above 5% can suppress pathogenic growth in the host. In crops such as stone fruits, a direct suppression occurs when fungal respiration and growth are reduced by the high CO_2 of the modified atmosphere. For example, CO_2 added to air has been widely utilized in the transport of 'Bing' cherries, primarily to suppress Gray Mold and Brown Rot. Low O_2 does not appreciably suppresses fungal growth until the concentration is below 2%. Important growth reductions result if the O_2 is lowered to 1% or lower although there is a danger that the crop will start respiring anaerobically and develop off-flavor. Other technologies that have been tested for lowering postharvest decay with limited success have been storage and transport under low O_2 and the use of carbon monoxide (Spotts, 1984; Sommer, 1989).

Postharvest Diseases of Fruits: Fruit crops are attacked by a wide range of microorganisms in the postharvest phase (Snowdon, 1990; Ogawa and English, 1991). Actual disease only occurs when the attacking pathogen starts to actively grow in the host. Diseases are loosely classified according to their signs and symptoms. Signs are visible growths of the causal agents, and symptoms the discernible responses produced by the host. In many diseases there is local discoloration and disruption of tissue, with the formation of obvious lesions. Postharvest diseases are caused primarily by microscopic bacteria and fungi, with fungi the most important causal agent in fruit crops. Fungi are further subdivided into classes and are described as lower fungi, characterized by the production of sporangia which give rise to numerous sporangiospores, or higher fungi, described as ascomycetes, deuteromycetes, and basidiomycetes. Ascomycetes are exemplified by fruiting bodies that release sexual spores when mature. Deuteromycetes, a form of ascomycete, only release asexual spores. They are more common than the sexual ascomycete stage in postharvest crops. Deuteromycetes are further subdivided into hyphomycetes and coelomycetes based on spore and structural characteristics. The agonomycetes contain important soil pathogens that form survival structures known as sclerotia that allow them to survive in the absence of the host. These fungi and the rust and smut fungi are examples of basidiomycetes. Table 1 lists many important diseases of fruit crops according to host and causal agents.

Postharvest Diseases of Vegetables: Postharvest diseases of vegetables are caused by microscopic fungi and bacteria (Snowdon, 1992; Howard et al., 1994). Bacteria are more common as pathogens of vegetables than fruit because in general vegetables are less acidic than fruit. They are visible under the light microscope as mostly single-celled rods. Bacteria are capable of very rapid multiplication under the right conditions of pH, temperature, and nutrition. They are classified according to their size, shape, reaction to certain stains, and behavior on various growth media (Krieg and Holt, 1984). The term "vegetable" encompasses a range of plant parts, and the common definition is a culinary one, denoting consumption as a savory rather than as a dessert food (Snowdon, 1992). Many vegetables are fruits in the botanical sense, with notable examples being tomatoes, peppers, squashes, and cucumbers. Table 2 lists many of the important diseases of vegetable crops according to host and causal agent.

New Directions for Postharvest Plant Pathology: Postharvest plant pathology has changed its emphasis in recent years. Food safety has emerged as a key element in decay control programs. Continued failure to effectively control certain postharvest diseases and the need for more environmentally friendly crop control materials is driving a new approach to disease control. Integrated postharvest decay control is the concept that offer the most promise for the future. Society can no longer rely on one or two control strategies but must enlist the entire spectrum of strategies to reduce postharvest losses.

Food Safety Issues: The two most important causes of unsafe food are microbial toxins (Hsieh and Gruenwedel, 1990) and contamination of horticultural products by fecal coliforms (Gould, 1973). The microbial toxins can be subdivided into bacterial toxins and toxins produced by fungi or mycotoxins. An example of a microbial toxin that is extremely toxic are the botulinum toxins produced by the anaerobic bacterium, *Clostridium botulinum*. Interest in toxins produced by fungi was stimulated by the death of 100,000 turkey poults in England in 1960. Aflatoxins produced by fungi in the peanut meal used to feed the birds was the cause. Studies have since shown aflatoxins to be potent carcinogens that may occur in nuts and grain (Phillips, 1984; Ellis et al., 1991). Other toxins have been identified that are produced by the same fungi that cause postharvest decay. For example, patulin produced by *Penicillium* and *Aspergillis* spp. can be found in apple and pear products. Patulin is toxic to many biological systems but its role in causing animal and human disease is unclear (Hsieh and Gruenwedel, 1990). Studies on contamination of horticultural products by fecal coliforms has increased dramatically because of documented incidences of food poisoning from apple juice and seed sprouts. Definite interactions have been shown between plant pathogens and foodborne human pathogens such as *Salmonella* and *Listeria*. A study, involving more than 400 samples each of healthy and soft rotted commodities collected in retail markets, indicated that the presence of *Salmonella* on produce affected by bacterial soft rot was twice that of healthy samples (Wells and Butterfield, 1997). Controlled experiments with potato, carrot and pepper tissues inoculated with a strain of *Salmonella* confirmed that bacterial soft rot infection increased multiplication of *Salmonella* by at least three- to ten-fold compared to multiplication on uninfected tissues. Similarly, populations of *Listeria monocytogenes,* inoculated into decayed apple tissue, continually increased on fruit decayed by *Glomerella cingulata,* but did not survive after 5 days on fruit decayed by *Penicillium expansum* (Conway et al.). The pH of the decayed area declined from pH 4.7 to 3.7 in the case of *P. expansum*, but in the case of *G. cingulata* pH increased from pH 4.7 to 7.0. This pH modification may be responsible for affecting growth of the foodborne pathogen. Contamination of produce with human pathogens is an important issue that must be addressed while at the same time limiting decay caused by postharvest pathogens and maintaining product quality.

Integrated Control of Postharvest Diseases: Effective and consistent control of storage diseases is dependent upon integration of the following practices:

Select disease resistant cultivars where possible.
Maintain correct crop nutrition by use of leaf and soil analysis.
Irrigate based on crop requirements and avoid overhead irrigation.
Apply pre-harvest treatments to control insects and diseases.
Harvest the crop at the correct maturity for storage.
Apply postharvest treatments to disinfest and control diseases and disorders on produce.
Maintain good sanitation in packing areas and keep dump water free of contamination.
Store produce under conditions least conducive to growth of pathogens.

Integration of cultural methods and biological treatments with yeast biocontrols has been studied on pears (Sugar et al., 1994). It was found that early harvest, low fruit nitrogen, high fruit calcium, yeast or yeast plus fungicide treatment, and controlled atmosphere storage all reduced severity of blue mold and side rot. These results demonstrated that unrelated cultural and biological methods that influenced pear decay susceptibility can be combined into an integrated program to substantially reduce decay.

In another example of an integrated strategy 'Gala' apples were heat treated at 38 ^{o}C (100.4 °F) for 4 days, followed by calcium infiltration with a 2% solution of $CaCl_2$ chloride, and then treated with the microbial antagonist, *Pseudomonas syringae* (Conway et al., 1999). The combined strategy was much more effective than any single strategy for the following reasons. Heat treatment reduced the pathogen population on the fruit surface but did not provide any residual protection. The residual protection was provided by calcium and the biocontrol agent added to the control provided by the heat treatment.

As a general rule, alternatives to chemical control are often less effective than many fungicides. It is highly unlikely that any one alternative method alone will give the same level of control as fungicides. Therefore, it will generally be necessary to combine several alternative methods to develop an integrated strategy to successfully reduce postharvest decay.

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Web Sites
A quickly changing resource on plant pathology: http://www.sci.soc.org
Postharvest information network: http://postharvest.tfrec.wsu.edu/
Postharvest technology research and information center: http://postharvest.ucdavis.edu/
Sidney postharvest lab with links to other sites: http://www.postharvest.com.au/Default.html

Table 1. Important postharvest diseases of fruit

Fruit	**Disease**	**Causal Agent**	**Fungal class/Type**
Avocado	Anthracnose	*Glomerella cingulata*	Pyrenomycete
	Cercospora spot	*Pseudocercospora purpurea*	Hyphomycete
	Dothiorella rot	*Botryosphaeria ribis*	Loculoascomycete
	Scab	*Sphaceloma persae*	Coleomycete
	Stem-end rots	*B. theobromae, Phomopsis perseae, Thyronectria pseudotrichia*	Deuteromycetes
Banana	Anthracnose	*Colletotrichum musae*	Coelomycete
	Cigar-end rot	*Trachysphaera fructigena, Verticillium theobromae*	Deuteromycetes
	Crown rot	*C. musae, Fusarium pallidoroseum, V. theobromae*	Deuteromycetes
	Finger rot	*B. theobromae*	Coelomycete
	Pitting disease	*Pyricularia grisea*	Hyphomycete
	Sigatoka disease	*Mycosphaerella* spp.	Loculoascomycete
Berries	Gray mold	*Botrytis cinerea*	Hyphomycete
	Leak	*Mucor* spp.	Zygomycete
	Leather rot	*Phytophthora* spp.	Oomycete
Citrus	Alternaria rot	*Alternaria* spp.	Hyphomycete
	Anthracnose	*C. gloeosporioides*	Coelomycete
	Bacterial canker	*Xanthomonas campestris*	Bacterium
	Black pit	*Pseudomonas syringae*	Bacterium
	Black spot	*Phyllosticta citricarpa*	Coelomycete
	Blue mold	*Penicillium italicum*	Hyphomycete
	Brown rot	*Phytophthora* spp.	Oomycete
	Greasy spot	*Mycosphaerella citri*	Loculoascomycete
	Green mold	*P. digitatum*	Hyphomycete
	Scab	*Elsinoe fawcettii*	Loculoascomycete
	Sour rot	*Geotrichum candidum*	Hyphomycete
	Stem-end rots	*D. gregaria, Phomopsis citri, B.theobromae*	Coelomycetes
Kiwi fruit	Gray mold	*B. cinerea*	Hyphomycete
Grape	Aspergillus rot	*Aspergillus niger*	Hyphomycete
	Blue mold	*Penicillium* spp.	Hyphomycete
	Gray mold	*B. cinerea*	Hyphomycete
	Rhizopus rot	*Rhizopus* spp.	Zygomycete

Mango	Anthracnose	*C. gloeosporioides*	Coelomycete
	Botryodiplodia rot	*B. theobromae*	Coelomycete
	Stem-end rots	*B. theobromae, Phomopsis* spp.	Coelomycete
Papaya	Anthracnose	*C. gloeosporioides*	Coelomycete
	Black rot	*Phoma caricae-papayae*	Coelomycete
	Phytophthora rot	*P. palmivora*	Oomycete
	Rhizopus rot	*R. stolonifer*	Zygomycete
	Stem-end rot	*B. theobromae, Phomopsis* spp.	Coelomycetes
Pineapple	Black rot	*Thielaviopsis paradoxa*	Hyphomycete
	Fruitlet core rot	*Fusarium moniliforme P. funiculosum*	Hyphomycete
Pome fruit (apple, pear)	Bitter rot	*C. gloeosporioides*	Coelomycete
	Black rot	*Sphaeropsis malorum*	Coelomycete
	Blue mold	*Penicillium expansum, Penicillium* spp.	Hyphomycetes
	Brown rot	*Monilinia* spp.	Hyphomycete
	Bull's-eye rot	*Cryptosporiopsis curvispora*	Hyphomycete
	Gray mold	*B. cinerea*	Hyphomycete
	Moldy core	*Alternaria* spp., others	Hyphomycetes
	Mucor rot	*Mucor piriformis*	Zygomycete
	White rot	*D. gregaria*	Coelomycete
Stone fruit (cherry etc.)	Alternaria rot	*A. alternata*	Hyphomycete
	Blue mold	*P. expansum*	Hyphomycete
	Brown rot	*Monilinia* spp.	Hyphomycetes
	Rhizopus rot	*Rhizopus* spp.	Zygomycete

Table 2. Important postharvest diseases of vegetables

Vegetable	**Disease**	**Causal Agent**	**Fungal Class/Type**
Bulbs (Onion, garlic)	Bacterial soft rot	*Erwinia caratovora*	Bacterium
	Black rot	*Aspergillus niger*	Hyphomycete
	Blue mold rot	*Penicillium* spp.	Hyphomycete
	Fusarium basal rot	*Fusarium oxysporum*	Hyphomycete
	Neck rot	*Botrytis* spp.	Hyphomycete
	Purple blotch	*Alternaria porri*	Hyphomycete
	Sclerotium rot	*Sclerotium rolfsii*	Agonomycete
	Smudge	*Colletotrichum circinans*	Coelomycete
Crucifers (Cabbage, etc.)	Alternaria leaf spot	*Alternaria* spp.	Hyphomycete
	Bacterial soft rot	*E. caratovora*	Bacterium
	Black rot	*Xanthomonas campestris*	Bacterium
	Downy mildew	*Peronospora parasitica*	Oomycete
	Rhizoctonia rot	*Rhizoctonia solani*	Agonomycete
	Ring spot	*Mycosphaerella brassicicola*	Loculoascomycete
	Virus deases	Cauliflower mosaic virus	

		Turnip mosaic virus	Virus
	Watery soft rot	*Sclerotinia* spp.	Discomycete
	White blister	*Albugo candida*	Oomycete
Cucurbits	Anthracnose	*Colletotrichum* spp.	Coelomycete
(Cucumber etc.)	Bacterial soft rot	*Erwinia* spp.	Bacterium
	Black rot	*Didymella bryoniae*	Loculoascomycete
	Botryodiplodia rot	*Botryodiplodia theobromae*	Coelomycete
	Charcoal rot	*Macrophomina phaseolina*	Coelomycete
	Fusarium rot	*Fusarium* spp.	Hyphomycete
	Leak	*Pythium* spp.	Oomycete
	Rhizopus rot	*Rhizopus* spp.	Zygomycete
	Sclerotium rot	*Sclerotium rolfsii*	Agonomycete
	Soil rot	*R. solani*	Agonomycete
Legumes	Alternaria blight	*A. alternata*	Hyphomycete
(Peas, beans)	Anthracnose	*Colletotrichum* spp.	Coelomycete
	Ascochyta pod spot	*Ascochyta* spp.	Coelomycetes
	Bacterial blight	*Pseudomonas* spp.	
		Xanthomonas spp.	Bacteria
	Chocolate spot	*B. cinerea*	Hyphomycete
	Cottony leak	*Pythium* spp.	Oomycete
		Mycosphaerella blight	
		M. pinodes	Loculoascomycete
	Rust	*Uromyces* spp.	Hemibasidiomycete
	Sclerotium rot	*S. rolfsii*	Agonomycete
	Soil rot	*R. solani*	Agonomycete
	White mold	*Sclerotinia* spp.	Discomycete
Roots/Tubers	Bacterial soft rot	*Erwinia* spp.	
- Carrots		*Pseudomonas* spp.	Bacteria
	Black rot	*A. radicina*	Hyphomycete
	Cavity spot	disease complex	Soil fungi
	Chalaropsis rot	*Chalara* spp.	Hyphomycetes
	Crater rot	*R. carotae*	Agonomycete
	Gray mold rot	*B. cinerea*	Hyphomycete
	Sclerotium rot	*S. rolfsii*	Agonomycete
	Watery soft rot	*Sclerotinia* spp.	Discomycete
Roots/Tubers	Bacterial soft rot	*Erwinia* spp.	Bacteria
-Potatoes	Blight	*Phytophthora infestans*	Oomycete
	Charcoal rot	*S. bataticola*	Agonomycete
	Common scab	*Streptomyces scabies*	Actinomycete
	Fusarium rot	*Fusarium* spp.	Hyphomycete
	Gangrene	*Phoma exigua*	Coelomycete
	Ring rot	*Clavibacter michiganensis*	Bacterium
	Sclerotium rot	*S. rolfsii*	Agonomycete
	Silver scurf	*Helminthosporium solani*	Hyphomycete
	Watery wound rot	*Pythium* spp.	Oomycete
Roots/Tubers	Black rot	*Ceratocystis fimbriata*	Pyrenomycete
-Sweet potatoes	Fusarium rot	*Fusarium* spp.	Hyphomycete
	Rhizopus rot	*Rhizopus* spp.	Zygomycetes
	Soil rot	*Streptomyces ipomoeae*	Actinomycete
	Scurf	*Monilochaetes infuscans*	Hyphomycete

Solanaceous (Tomato, pepper, eggplant)	Alternaria rot	*A. alternata*	Hyphomycete
	Anthracnose	*Colletotrichum* spp.	Coelomycete
	Bacterial canker	*C. michiganensis*	Bacterium
	Bacterial speck	*Pseudomonas syringae*	Bacterium
	Bacterial spot	*X. campestris*	Bacterium
	Fusarium rot	*Fusarium* spp.	Hyphomycetes
	Gray mold rot	*B. cinerea*	Hyphomycete
	Late blight	*P. infestans*	Oomycete
	Phoma rot	*Phoma lycopersici*	Hyphomycete
	Phomopsis rot	*Phomopsis* spp.	Coelomycetes
	Phytophthora rot	*Phytophthora* spp.	Oomycete
	Pleospora rot	*Stemphylium herbarum*	Hyphomycete
	Rhizopus rot	*Rhizopus* spp.	Zygomycetes
	Sclerotium rot	*S. rolfsii*	Agonomycete
	Soil rot	*R. solani*	Agonomycete
	Sour rot	*Geotrichum candidum*	Hyphomycete
	Watery soft rot	*Sclerotinia* spp.	Discomycetes
Miscellaneous			
- Artichokes	Gray mold	*Botrytis cinerea*	Hyphomycete
	Watery soft rot	*Sclerotinia sclerotiorum*	Discomycete
- Asparagus	Bacterial soft rot	*Erwinia* or *Pseudomonas* spp.	Bacteria
	Fusarium rot	*Fusarium* spp.	Hyphomycete
	Phytophthora rot	*Phytophthora* spp.	Oomycete
	Purple spot	*Stemphylium* spp.	Hyphomycete
- Celery	Bacterial soft rot	*Erwinia* or *Pseudomonas* spp.	Bacteria
	Brown spot	*Cephalosporium apii*	Hyphomycete
	Cercospora spot	*Cercospora apii*	Hyphomycete
	Gray mold	*Botrytis cinerea*	Hyphomycete
	Licorice rot	*Mycocentrospora acerina*	Hyphomycete
	Phoma rot	*Phoma apiicola*	Coelomycete
	Pink rot	*Sclerotinia* spp.	Discomycete
	Septoria spot	*Septoria apiicola*	Coelomycete
- Lettuce	Bacterial rot	*Erwinia, Pseudomonas, Xanthomonas* spp.	Bacteria
	Gray mold rot	*B. cinerea*	Hyphomycete
	Rhizoctonia rot	*R. solani*	Agonomycete
	Ringspot	*Microdochium panattonianum*	Hyphomycete
	Septoria spot	*S. lactucae*	Coelomycete
	Stemphylium spot	*Stemphylium herbarum*	Hyphomycete
	Watery soft rot	*Sclerotinia* spp.	Discomycete